THE

Mount Royal Tunnel

MONTREAL, QUEBEC
CANADA

BEING BUILT BY

Mackenzie, Mann & Company, Limited

FOR

The Canadian Northern Montreal Tunnel and Terminal Co., Limited

AS AN ENTRY INTO MONTREAL

FOR

The Canadian Northern Railway

Land Department
Davidson & McRae, General Agents
230 St. James St., Montreal, Canada.
December, 1913

NOTE

The Name "**Canadian Northern Montreal Tunnel and Terminal Company, Limited,**" has been changed to

"**MOUNT ROYAL TUNNEL AND TERMINAL COMPANY LIMITED**"

January, 1914.

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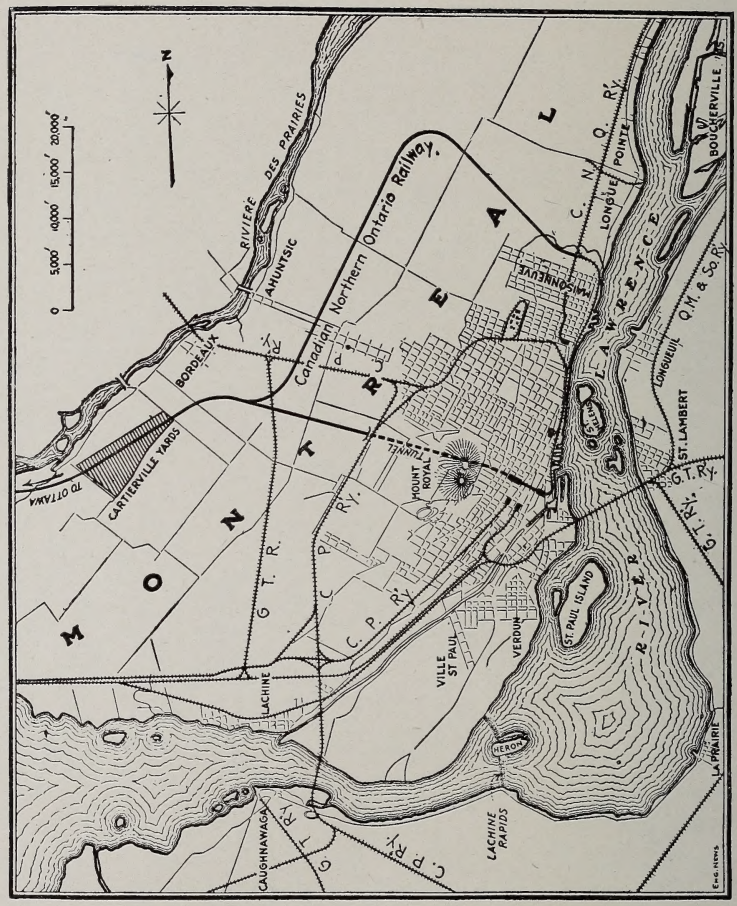


Figure 1.—General Plan of Terminal Connections, Montreal.

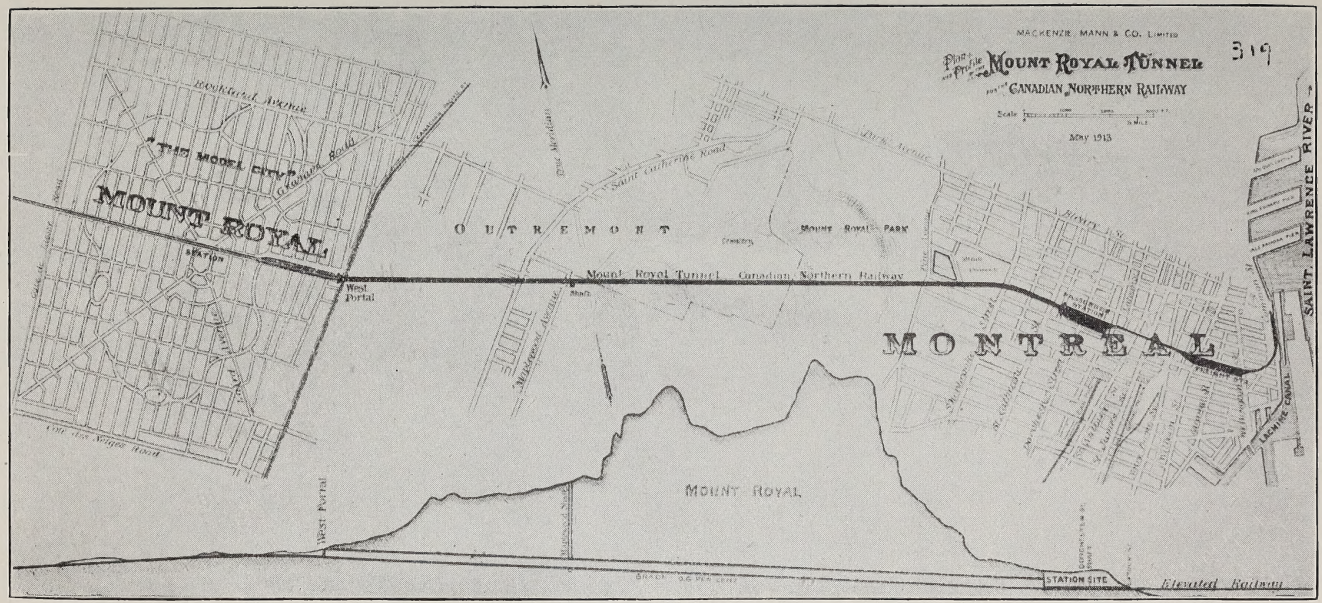


Figure 2.—Plan and Profile of Mount Royal Tunnel.

See Synopsis and Quantities in back

General Description

The Canadian Northern Railway now has under contract about 2,500 miles of railroad, which when finished will complete its Transcontinental System, with a total mileage of over 10,000. The greater part of this mileage is in the grain fields of the middle West, where that great mass of traffic originates which has made Montreal the second busiest harbor on the American continent.

It is largely this enormous grain traffic, amounting often to over 1,000,000 bushels of wheat alone per day, that has enabled the Canadian Northern to pay the interest on its bonds, invariably, the first year of operation, on every line opened in the West. In regard to economy of operation it is also interesting to note that the Canadian Northern Transcontinental line not only has the flattest grades but also the lowest summit of any line crossing the Rocky Mountains. When this line is completed in 1914 it will be the second transcontinental system to be operated in Canada.

With this immediate completion in view it became imperative to develop such terminal facilities in Montreal (see figure 1) that this new artery should never become congested and that the ever-increasing traffic should be encouraged to the fullest extent. In this the forehanded policy of the Montreal Harbor Commissioners and the progressive character of their Chief Engineer, was a great incentive, their plans anticipating extensions and improvements with which the Canadian Northern was most heartily in accord.

Montreal now has a population approaching 800,000, and is increasing at the rate of nearly 10% per annum. Of this population nearly 75% is of French extraction. The city is divided into two principal levels—the commercial and financial quarter being on a plain only a few feet above high water, and the residential and shopping district, being on a plateau about 75 feet above the river. In general, the French live to the East and North, while the English-speaking population live in the Southwesterly part of the city and on the higher slopes of Mount Royal.

As the space between Mount Royal and the St. Lawrence River is very limited, this district has become very congested. Business has largely forced the residence section up and down the river and around the Mountain. An entry from either end of the narrow strip would have been very difficult and expensive in many ways, and, as the Canadian Pacific Railway and Grand Trunk Railway already had lines entering in this manner, no advantage could thus be gained.

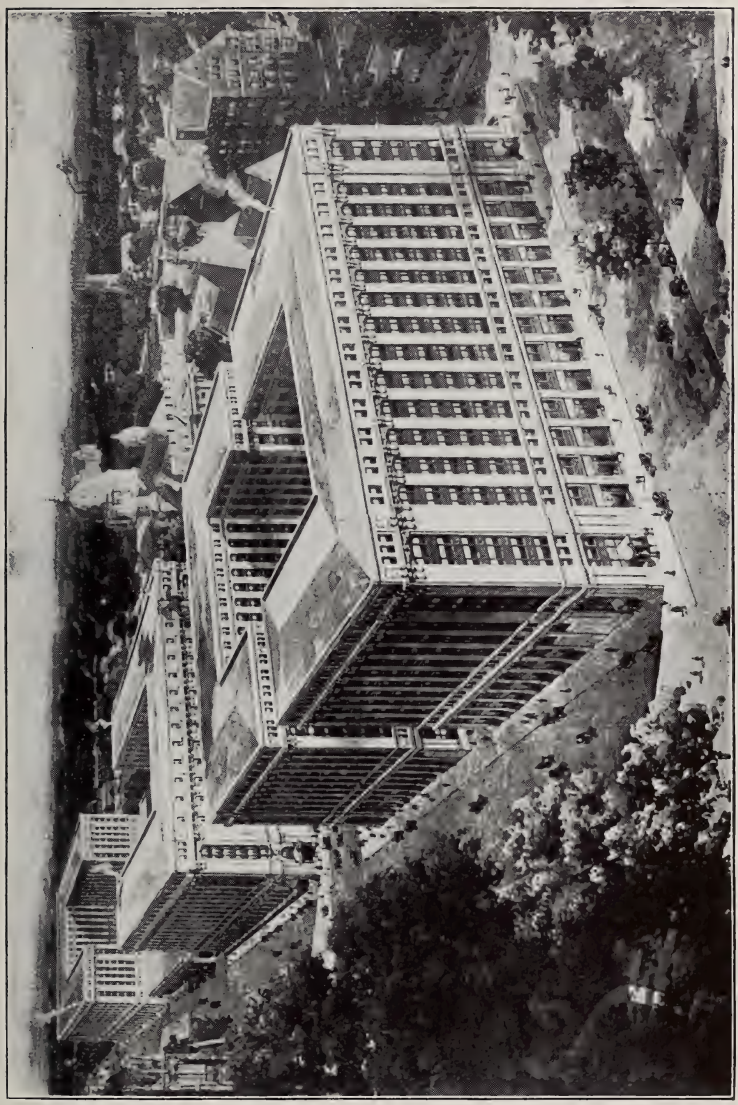


Figure 3.—Proposed Buildings for Canadian Northern Passenger Terminal, Warren & Wetmore, Architects.

On the other hand, by tunneling straight through Mount Royal (see figure 2), the Passenger Terminal could be located in the very centre of the most desirable section, midway between the two levels, and equally convenient to the English and French parts of the city. Furthermore, in the same direct line and without change of grade, the tracks could be carried from the Passenger Terminals across the lower town on an elevated viaduct to connect with the Harbor Commissioners' proposed viaduct; thus giving direct access to the Canadian Northern Transatlantic Steamships, all ordinary harbor facilities and a possible bridge across the St. Lawrence River. Connected with this viaduct an elevated Freight Terminal is planned in the centre of the commercial district, for the acceptance and delivery of local freight.

The Passenger Terminal is located between Cathcart and Lagauchetiere, St. Monique and Mansfield Streets. Its platforms, which are about 1,200 feet long, will be 45 feet below the upper level at Dorchester Street, and 20 feet above the general lower level of the town. Its entrances will be so arranged above and below as to automatically segregate the express from the commuter traffic.

The Terminal buildings (see figure 3) will be, architecturally, one of the most attractive groups of a commercial nature in Canada. They will, however, be of a purely utilitarian character. It is expected that, apart from the Railway business, the income from these buildings alone, will go far towards making the Terminal developments self-supporting.

Much credit for both the conception and realization of this most ingenious entry is due to H. K. Wicksteed, Chief Engineer of Surveys for Mackenzie, Mann & Co., Limited, who, with the principals, conceived the plan in its entirety.

Mount Royal, "The Model City."—Back of the Mountain, on the lower slopes, a large tract of farm land was bought, extending Northwesterly to the Back, or Ottawa River. Much of this land, which is not needed for shops, yards, and other railroad services, has been subdivided and is being sold in city lots; in fact, the "Model City" of Mount Royal has already been incorporated as a town. As the tunnel will bring this locality within less than ten minutes of the very centre of Montreal, the property has already become very valuable. Thus it is expected that the land will more than pay for all the Terminal development in and about Montreal. It is interesting to note that banks and churches were among the first to take land in the "Model City."

Mount Royal, as incorporated, is about one and a half miles in width by two miles, and has not a gully, hill, ravine, nor any low, wet land in the whole town site. The entire property slopes towards the Back River, with an average drop of thirty-five feet to the mile. This Piedmont country was the land so famous for its Montreal Melons. It is very fertile and was the most prosperous farming section about Montreal. Its natural drainage lends itself peculiarly to modern municipal sanitation and the geological structures, consisting of solid hard pan only a few feet below the

surface, will be invaluable for cheap and easy building foundations. This point is particularly appreciated by people in Montreal who are familiar with the soft and shifting leda clay so common to the city side of the Mountain.

Departing from the usual arrangement of having all cross streets run at right angles, the plan provides for diagonal business streets which converge to the central station. This will permit easy and rapid access to the trains from any point. As all public utilities, such as water, sewerage, electric wires, etc., are restricted, where possible, to the alleys, which run through the centres of all blocks, the street pavements will not be continuously broken up and under repair from this source as is so common in the usual city street.

Four streets have been reserved for business purposes, namely:— Graham Road, Laird Ave., Canora Ave., and Rockland Ave. These are the only streets where it is possible to erect solid rows of buildings, and it is only on these streets that permits may be obtained for Flats and Apartments. The balance of Mount Royal will be restricted to high class residential buildings. Each residence must be at least two stories in height, built of stone, brick or cement, on stone, brick or cement foundations, at least fifteen feet from the street line; any out-buildings must be at least seventy feet from the street line. Only detached or semi-detached residences will be permitted. Proper restrictions regulating the cost of buildings will also tend to keep the standard high.

The following extract from the building restrictions is illustrative of this feature.

"The Purchaser shall not erect, or permit to be erected on said emplacement, or carry on or permit to be carried on thereon any manufacturing factory, apartment house, flats, slaughter house, cow-byre, piggery, hospital, medical school, incinerator, livery stable, or private stable having more than three single stalls; wood, lumber, brick or coal yard, lime kiln, or any other manufacture or business which the Company may declare detrimental to the sale or value of the adjacent property, without its written consent." These restrictions, it should be noted, become part of the Deeds of Sale, and are therefore perpetual.

Each residential street is sixty-six feet wide, and the diagonal business streets are eighty feet in width. The Boulevard, which is sixty-six feet in width, encircles the property, and thirteen large parks have been provided.

All residential lots are fifty feet wide and vary from ninety-five to one hundred and ten feet in depth. The business lots will average thirty-three by one hundred and twenty feet.

A local station called "Mount Royal Heights" will be built where the Canadian Northern line crosses under the Canadian Pacific Railway's belt line, at the West Portal of the Tunnel. There will be entrances to the Station on the Model City side of the C.P.R. The main station, however, back of the Mountain will be in the centre of the town of Mount Royal.

"A"—Igneous Dykes in Trenton Limestone. After the Mountain had been shattered by an eruption this trap flowed into the cracks forming the dykes.

"B "Camptonite Breccia. The black rock in this conglomerate is Camptonite Trap which has flowed about the shattered limestone marmorizing it by the terrific heat, the white rock being marble.

Figures 4.—IGNEOUS INTRUSIONS

GEOLOGICAL CONDITIONS OF THE TUNNEL

Mount Royal, about 700 feet high, is the result of a volcanic intrusion of igneous rock forced upward through the original bed of Trenton limestone. Whether it was ever an active volcano is doubtful, as there is little evidence of lava, although it may have been scoured away by glacial, or other action, at the same time that the higher portions of the mountain were similarly eroded. There have evidently been several stages of eruption or intrusion, as both the limestone and main igneous body of so called Essexite are broken and cut by a multitude of dikes and sheets of quite different character and evidently later origin. The Trenton limestone, at a considerable depth, is found to be hard and crystalline, and is an excellent rock for tunneling. This rock, when in close proximity to a large igneous body, is sometimes highly impregnated with epidote, quartz, garnet, and other minerals.

At the city end, going west from Dorchester Street, the heading for the first 2,000 feet is in a soft black limestone, somewhat blocky and in places partially disintegrated, with occasional stretches of earth roof. The earth, above the limestone, consists of sandy clay, boulder clay, occasional layers of hard pan, fine sand and large bodies of blue leda clay. This being under the city proper, forms the most difficult ground and conditions to be encountered, and a roof shield will be used.

As the rock cover increases the rock becomes harder and more dikes of extremely hard igneous rock, principally Bostonite, Camptonite and Nepheline Syenite are encountered. By the time 3,000 feet of heading had been driven, from Dorchester Street, the heading (except for the dikes) was in good, sound Trenton limestone, becoming more crystalline. It was in this that the record progress mentioned later was made.

The Essexite is very hard, containing Plagioclase Felspar, Pyroxene, Hornblend, Magnetite and Nepholine, aside from this it is a good tunneling rock.

The greatest difficulty encountered in drilling and excavating is due to the irregularity of the structure. Some of the limestone is so impregnated with various contact minerals that it is extremely hard to drill and some breccia is so broken and uneven that in places one hole would be lost out of three started. The worst trouble, however, occurred when large dykes were encountered which necessitated entirely changing the temper of the steel used; for instance, in the heading going East from the West Portal a dyke of porphyritic Camptonite, an extremely hard rock, four feet thick, continued in the face for 400 feet. Here two tempers of steel were required in the heading all the time. This greatly retarded the progress and materially increased the cost of excavation.

Another very difficult rock is a marmorized Limestone that was found in heading No. 1-W. This marble is impregnated with quartz and a natural cementing material that makes it hard to drill and causes the muck to set up so rapidly that it is very difficult to shovel into the cars.

In general, the Trenton limestone is an excellent tunneling rock although the roof is sometimes inclined to scale badly and where this ground is cut by dykes the Tunnel walls are apt to be insecure. When this limestone is badly distorted by neighboring igneous intrusions it is apt to be filled with internal strains which cause it to crack and fall making it rather treacherous and requiring heavy timbering and masonry lining.

Often, especially in the limestone, cavities are found filled with calcite crystals of both the dogtooth and nailhead pattern. Here too, is found a good deal of saponite and pyrites in various forms. Considerable Dawsonite, Feldspar, metallic arsenic and gypsum have been found from time to time, but not in quantities to be commercially valuable.

TUNNEL LOCATION

The location of the tunnel under Mount Royal was established more or less by the location of the passenger terminal in Montreal and the "Model City" at the back of the Mountain. For many reasons, a tangent from the central station in the "Model City" to the passenger terminal in Montreal would have been most desirable. But as this would have necessitated passing under much valuable property with very light cover, it was thought best to abandon it. This line would also have passed through a large body of Nepheline Syenite, which is a very hard rock.

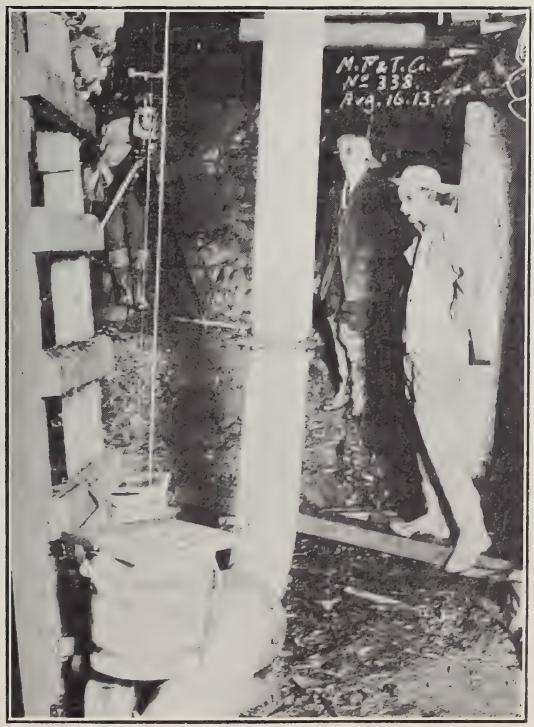
It was known that the heart of the mountain was a hard igneous Essexite, as above described, and that Camptonite breccia outcropped near the west portal. While this lower ridge of breccia and hard rock could not have been avoided without seriously affecting the lay-out of the "Model City," a portion of the hard rock in the centre of the mountain could have been avoided had it been considered expedient. The line finally adopted is $3\frac{1}{10}$ miles long and is the shortest line possible between the two main objective points, that could be devised to avoid surface obstructions and take advantage of the geological formation. This gives, economically, an extremely good tunnel line, which (with the exception of one curve under the McGill University grounds) is all on a tangent and has only sufficient grade (0.6% down toward the city) to insure proper drainage.

Surveys and Alignment.—Tunnel surveying is interesting, principally on account of the accuracy required and the many opportunities for the exercise of ingenuity.

It consists primarily of definitely locating and mapping all the topographic features in the immediate vicinity of the proposed line. Upon the maps thus prepared, the best positions for the openings such as shafts and portals can be fixed upon, the best underground route for the tunnel laid down, and the design of its construction determined.

The alignment parties give the direction for excavation and all points for placing the construction. In order to get the true direction and

A—Measuring.



B—Shaft Plumbing

Figure 5.—ALIGNMENT SURVEYS

distance from one opening to another it is necessary to have their position on the ground accurately determined. This requires careful measurement and angle reading. As the work progresses the calculated courses and distances between the shafts or portals are placed in the openings and the direction in which to excavate shown to the rock drillers. Careful steel tape measurement is often called base-line measurement, as many base lines for triangulation work are determined with the same methods. The careful measurement was made in this case along the paved streets on the north side of Mount Royal. On this work the steel tapes used were compared with a special tape standardized at the Bureau of Standards in Washington, D.C., at a given tension and temperature. In the surveys the readings were always taken at the standard tension and corrections made for temperature. The tapes were stretched across movable brass headed monuments, called spiders, set upon transit lines. The levels of the spiders were taken to correct for inclination. The standard tension in the tape was maintained by a standard weight suspended over an inverted bicycle wheel (see figure 5). The tape was supported every 20 feet, which was also standard. After the traverses had been completed a transit line was thrown over the mountain on the tunnel tangent line as a check with very satisfactory results.

After the places of entry had thus been located, and lines in the vertical planes of the tunnel axes had been established, points were fixed from which sights could be projected directly into the tunnel. The lines were projected down the shafts by means of heavy plumb-bobs suspended on fine piano wire. These wires were lined up at the top of the shafts from the fixed points on the surface line and at the bottom the direction was taken off the wires and projected into the tunnel. The plumbs were suspended in tubs of water and oil to retard osscilation. In the present case this work was somewhat more complicated than it sometimes is, on account of the necessity of locating the shafts on the Company's property, which was not directly over the tunnel. This made some sharp curves and short sights in the headings at the foot of the shafts to get to the tunnel line.

The primary excavation consists of a heading, or small tunnel, about 9 feet in height by 12 feet wide, driven on the centre line of the main tunnel, which is about 22 feet high by 30 feet wide. As this is a bottom heading, i.e., driven along the sub-grade of the tunnel proper, the permanent monuments are placed in the bottom of the heading, where they will not have to be disturbed. Only temporary wooden plugs with steel spads, i.e., nails with perforated heads to suspend sighting lamps on, with occasional brass vernier scales are placed in the roof. The plugs with spads are placed about every 50 feet in the heading on the engineer's line, and by knowing the relation of this line to the tunnel centre-line, and the various elevations of the spads, the alignment and grade of the heading may be maintained with considerable accuracy.

In all tunnel surveying, patience and continuous repetition is the key to success. All lines must be checked and re-checked, and readings made

again and again by independent observers, so as to rectify errors and produce the greatest accuracy possible. This is especially important in the underground work where no outside check can be obtained until the headings meet.

The methods just described have worked out very satisfactorily in the present case. The Maplewood Avenue shaft is one mile from the west portal. The shaft is about 240 feet deep, and the plumbing wires were only 13 feet apart. The shaft is off line and requires short reverse curves in transferring the lines from the shaft to the tunnel. When the heading coming from the west portal met that being driven from the Maplewood Avenue shaft, on April 5, 1913, the lines checked within 1-16 inch in alignment and ¼ inch in grade. Where the headings between the Maplewyod Avenue shaft and Dorchester Street shaft met, under the highest point of Mount Royal, on December 10th, 1913, the error was about three-quarters inch in line and one-quarter inch in grade.

TUNNEL CROSS-SECTIONS

The types of tunnel cross-section finally adopted, while bearing many points of similarity to various other tunnels already in existence, have a few novel features that are believed to be a step in advance in that particular branch of railway engineering.

In the studies for this design, the maximum equipment of American roads was summarized, and actual clearance and equipment diagrams of many of the most representative roads were studied and superimposed. In this manner a diagram of minimum clearance and a diagram for maximum equipment were evolved, for all cars likely to pass through the tunnel. It was found that a few freak cars, of exceptional width, had to be eliminated, but these were very few, of a class not likely ever to appear, and which had not been allowed for on other important roads.

A twin section was chosen for three primary reasons: (1) economy in construction; (2) ease and economy in ventilation; (3) protection and safety in case of derailment or accident.

1. **Economy in Construction.**—It was found that in soft ground the amount of both excavation and masonry could be reduced by adopting this twin section. The geological formation also indicates that in much of the rock, cut at the angle made by the present tunnel location, a centre wall will sufficiently reinforce the natural rock roof slab to eliminate the necessity of further lining without excavating a high rock arch.

2. **Ventilation.**—It is needless to say that a twin tunnel with all the traffic in each tube going in the same direction, is infinitely better for ventilation than a double track tunnel, where passing trains merely tend to stir up the air, without causing any positive and continuous movement

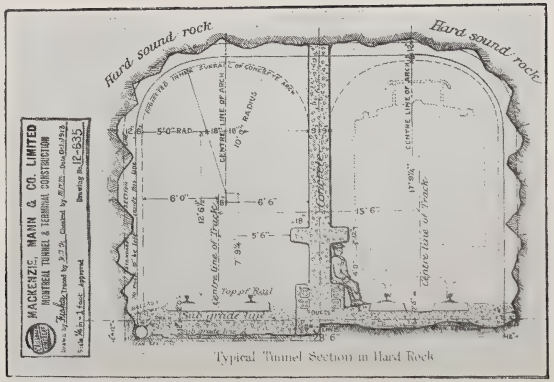

Hard sound rock
Hard sound rock
MACKENZIE, MANN & CO. LIMITED
MONTREAL TUNNEL & TERMINAL CONSTRUCTION
Typical Tunnel Section in Hard Rock

Figure 6—Tunnel Cross Section in Hard Sound Rock requiring no lining.

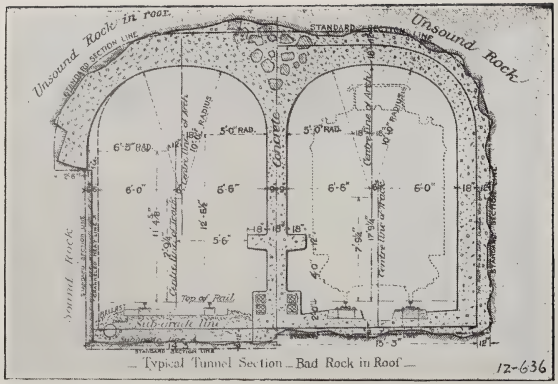


Figure 7—Typical Tunnel Section, Bad Rock in Roof.

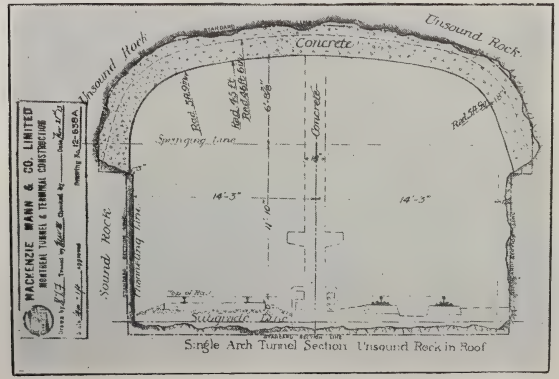


Figure 8—Single Arch Tunnel Section, Unsound Rock in Roof.

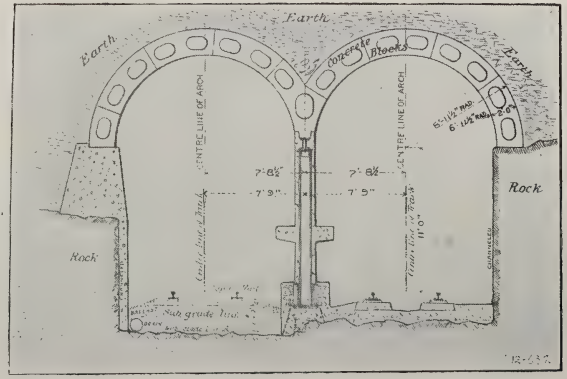


Figure 9—Tunnel Cross Section in very Soft Ground requiring Shield, Concrete Block Lining.

in any one direction. The cross-section of each tube is so proportioned that the relation of train area to tube area will materially encourage ventilation without producing excessive compression, which would retard the velocity of trains and might be objectionable to passengers.

3. **Safety.**—The centre wall is particularly valuable in case of derailment or accident, there being no possibility of trouble on one track blocking both. Furthermore, having a walkway at about the platform level, it is possible for passengers to get out of the cars, in natural and orderly fashion, in case of stoppage and walk to the nearest cross passage, where they can enter the adjoining tube. This walkway is made narrow so that people must pass along in single file, the idea being to avoid the danger of crushing and panic.

The normal clearance at the walkway edge is 2 in. greater than that of the normal high passenger platform adopted in the terminal station, and 3 in. greater than that allowed on the New York Central R.R. and Pennsylvania R.R. lines about New York. The walkway edge also coincides with the clearance lines (outside of platform) of the Pennsylvania R.R. (lines east of Pittsburg), including the through lines between New York and Pittsburg.

Underneath the walkway is a continuous refuge niche, except at splicing chambers, where trackmen may sit on the duct bench, at the bottom of the dividing wall, and be absolutely protected from passing trains. Large refuge niches will be built occasionally in the outside wall for the accommodation of hand cars and repair equipment during hours of train operation. The outside wall clearance is coincident with the clearance for new structures in the New York Central R.R. terminal work in New York, and is in excess of the clearance of the Pennsylvania R.R. lines east of Pittsburg.

A high headroom was adopted as provision for a high-voltage trolley. The flattened three-centre arch was adopted: (1) to allow for the sway of the pantograph; and (2) on account of the stratification of the rock, where much of the lining will occur, which lends itself peculiarly to a flat roof (see figures 6 and 7). In the soft ground on the city end, where a roof shield is to be used, twin semi-circular arches will be used slightly higher and wider than the standard section. This change in shape and size was adopted on account of ease and safety in construction. (See figure 9.)

The floor and track construction will be of two types: (1) creosoted ties, with tie-plates and screw spikes, laid in a deep trough of ballast; (2) a fixed grade and alignment, produced by rail supports rigidly fastened to a concrete bed. The former, used under the city proper, is designed to produce the least possible vibration. The latter type being for stations, and in the major part of the tunnel, is designed for small maintenance cost with perfect grade and alignment.

The general cross-section, as above described, will vary materially, in certain details, with the character of the ground through which the tunnel

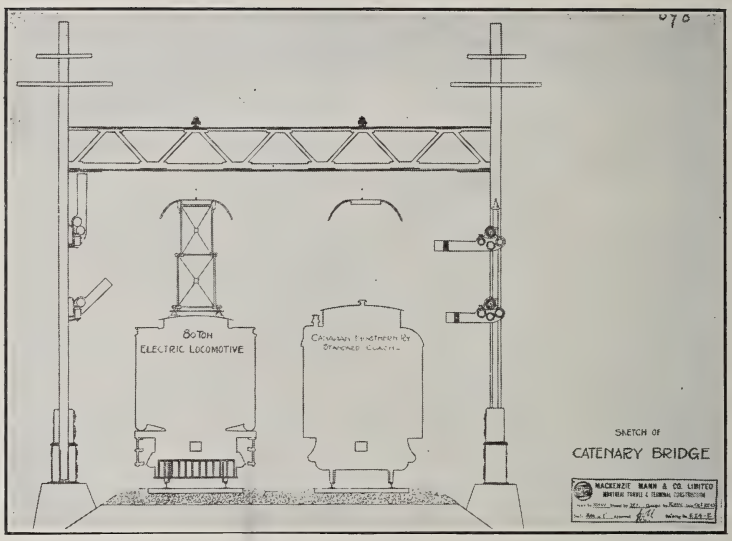


Figure 10—Outside Bridge construction for contact circuit.

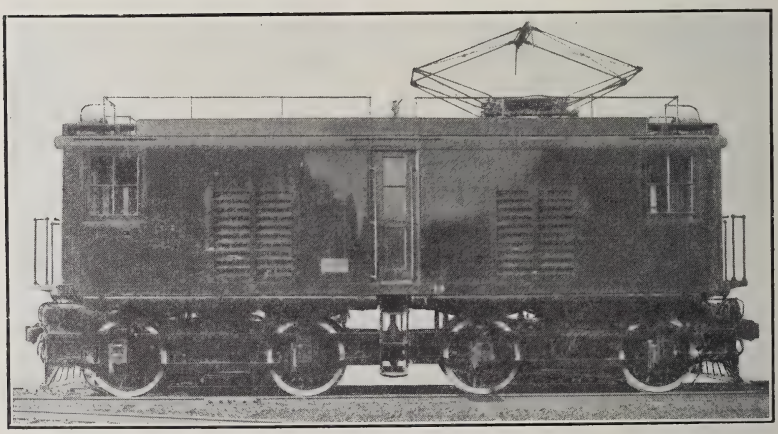


Figure 11—80 Ton, 2,400 Volts, Direct Current, Electric Locomotive to be used on Montreal Electrification.

passes. Where the roof is bad, and the sides are in good rock, the side-wall concrete may be omitted, where the rock caves in the roof a double track arch may be used (see figure 8). As the work is being done by Mackenzie, Mann & Co., Limited, who control the Canadian Northern, with one organization for both design and construction, every flexibility in design may be taken advantage of for economy in construction.

ELECTRIFICATION

All trains through the tunnel will be operated electrically. Locomotives will be used to haul Transcontinental, Express and Local traffic, which extends beyond the "Electric Zone," and Multiple unit motor cars will be used for the traffic inside that boundary.

The Locomotives are 80 ton (see figure 11) and capable of producing a speed of 50 miles an hour The heaviest trains will be 16 car Transcontinentals, the rated speed being 30 miles with two locomotives. The Multiple unit cars are 60 ton cars with a speed of 45 miles per hour and a seating capacity of 70 passengers. These cars can also haul one trailer if desired. All steel cars will be used.

The power used will be 2,400 volts direct current. All motors are wound for 1,200 volts and insulated for 2,400 volts, and are operated two in permanent series. The contact circuit will be of the overhead catenary type, the character of the climate making a third rail inadvisable outside the tunnel. (See figure 9.)

A substation for power conversion will be built near the West Portal of the tunnel. If the Company develops its own power, or buys its power, where there is doubt of continuous service a steam auxiliary plant will be built near the Back River. Near the Back River, too, will be the Cartierville Yards where most of the freight will be sorted and the transfer made from steam to electric traction. Here also complete repair shops will be erected

The signals will be of the automatic block type with a special safety device by which a train is automatically brought to a stop if the Engineer inadvertently runs by a block signal that is set against him.

On the Multiple unit cars special safety appliances are arranged so that if the motorman collapses for any reason, the train is brought automatically to a stop, and by certain door connections no train can start until all doors are closed.

EXCAVATION AND CONSTRUCTION

There are many methods of tunneling, usually known by the name of the country in which they originated or have been most commonly applied. The so called American method is the top heading and bench method, where a small tunnel or heading is driven in the upper half of

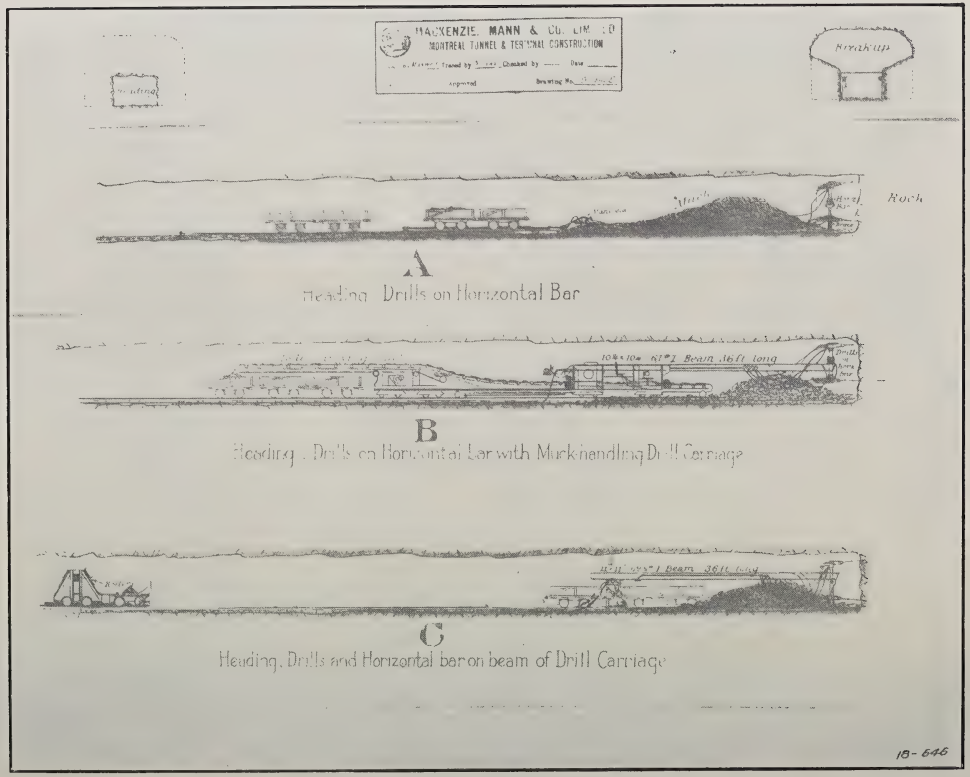


Figure 12—**Typical Heading Procedure.**

the tunnel section and the bottom portion or bench is removed later, often with a steam shovel, where the character of the ground permits. This is often very economical and has many points of advantage over other methods where the ground makes it advisable, but it is not as fast as some of the European methods, which have been developed for long tunnels where time was of very great importance.

Time being of vital importance in the Mount Royal Tunnel it was decided to adopt a bottom centre heading which could be driven ahead rapidly, without much regard for the character of the ground, and from which the full-sized excavation could be developed at as many places simultaneously as desired.

Heading Excavation.—The headings are driven 8 to 10 feet high by 12 to 14 feet wide (over 50% larger than the headings of the principal Alpine tunnels) for the sake of ultimate economy. While this somewhat reduces the rate of progress, it very much decreases the cost of further excavation and construction; permitting reasonably broad-gauge double track through the break-ups, where the full size tunnel section, 22 feet high by 30 feet wide, is developed.

In the headings three principal methods have been used (see figure 11).

"A" Figure 12 shows the method where the rock was not so hard as to require an excessively heavy drilling equipment. The drills are mounted on a horizontal bar and the equipment is handled in and out of the heading by hand.

During this stage at the city end the heading cross-section was reduced to about 8 by 12 feet for the sake of rapidity in progress. (See figure 13.) Here no drill carriage was used, as much lighter drills were required, and a progress of 810 feet was made in the 31 working days following May 1st. This is the greatest linear progress ever made in a hard rock heading on this continent and has only been exceeded in Switzerland.

Four drills are used in each heading, supported on a horizontal bar. These drills are operated by compressed air at about 100 lbs. pressure per square inch. Each drill is fitted with special connection so that water may be forced through the piston and drill steel, which are hollow, into the bottom of the hole being drilled, thus keeping it cool and clean.

It is also interesting because both the linear feet of drilling (about 650 feet per 24 hours) and cubic yards of excavation (93 cubic yards per day) exceed anything ever accomplished in the European tunnels.

As the headings got into the hard igneous rock heavier drills were required, so that the total drilling equipment, including drills, saddles, arms and bar, weighed several tons. To carry this mass two types of drill carriages were devised (see figure 12). Each carries the drill bar on a long cantilever arm having a reach of over 20 feet beyond the carriage and is so arranged that the drills never have to be dismounted from the bar nor disconnected from the hose-manifold which is fastened to this cantilever arm. Thus the only connections to be made, when moving out or setting

Figure 13.—Heading Excavation Without Drill Carriage.

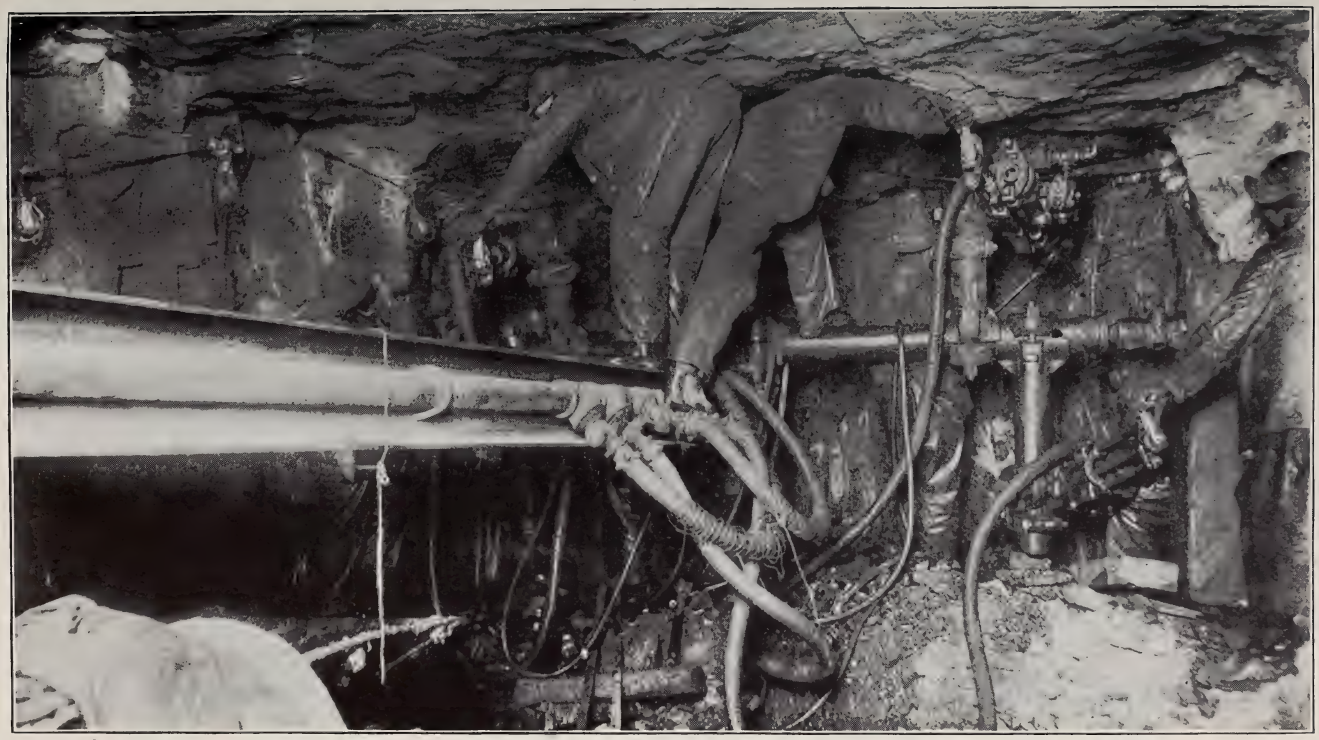


Figure 14.—**Heading Excavation Using Muck Handling Drill Carriage.**

up, are the main air and water hose to the pipe lines entering the heading, and the only labor is that of jacking the horizontal drill-bar tightly into position after it has been brought in and placed by the drill carriage.

All drill carriage track is riveted to steel plates so that the track may be cleared rapidly to within about 25 feet of the face after each shot, merely throwing the muck right and left. In the case of the muck-handling drill carriage the track is laid on one side of the heading while the other has its track down the centre. These machines save wear and tear on both men and machines, and make a surprising difference in the efficiency of both. With these machines the drills are in the heading ready to be jacked into place by the time the drillers have the loose rock barred down from the sides and roof and the muck thrown back sufficiently from the face to enable the bar to be set. Thus the time spent in setting up and taking down is much reduced. It is also notable that less muckers are required with this system than before the drill carriages were installed.

One drill carriage (see "B" figure 12) is so designed that the cantilever arm is given its motion, longitudinally, transversely and vertically by motor driven attachments. This machine remains in the heading after the drills are placed and has a belt conveyor running through it longitudinally about 18 inches above the track, which elevates and dumps the muck into cars in the rear. This was used in heading No. 3-E (see figure 14).

The effect of installing the muck-handling drill carriage is shown to a remarkable degree by the difference in progress obtained without any increase in force. For the six months prior to its installation the average progress in this heading was 350 feet per month. For the six months after the installation of the drill carriage the average progress has been 485 feet per month. This is an increase of 38%. Furthermore, it must be remembered that before the drill carriage was installed the heading was in limestone, for the greater part, while the drill carriage has been working almost exclusively in Essexite. The best month, May, 1913, was 510 feet in 27 working days. This heading is 10 feet high by 12.5 feet wide.

The average yardage removed from this heading, including the 4 Break-ups now working, is about 500 cubic yards, place measurement, per day. The linear progress in these Break-ups is about twice that of the heading.

The other drill carriage used in heading No. 1-W (see figure 15) has no motor attachment and is removed from the heading after the drills are placed (see "C" figure 12) leaving the cantilever arm attached to the drill bar and supported on a gallows frame which leaves the heading open for mucking (see figure 16). In this case the cantilever arm is advanced by the locomotive which pushes the drill carriage into the heading. The lateral and vertical movement are obtained by jacks and by hand. The progress with this carriage is almost identical with that of the other.

The average progress over the entire job since the headings were started in the tunnel has been 420 feet per month in each heading. This makes no allowance for delays or lost time. It must also be remembered

Figure 15—Heading excavation using Drill Carriage without conveyor.

Figure 16—Heading Excavation, Rear End of Cantilever beam of drill carriage without conveyor, carriage removed for mucking and drilling in operation.

that for six months on the city end the blasting was restricted between the hours of 11 p.m. and 7 a.m. to avoid public annoyance. The average progress, where blasting has been unrestricted, has been 430 feet per month in each heading. From the time the first heading was started in the tunnel until the final meeting almost exactly fifteen months have elapsed, giving a gross progress of 1,100 feet per month.

The general heading procedure is as follows:—

After a round of blasts has been completed the loose rock is barred down from the roof and sides and the muck (i.e., the broken rock) is thrown back from the face sufficiently to permit the horizontal bar and drills to be set up. These are erected, connected with the air and water lines and drilling commenced. From 18 to 24 holes, 5 to 8 feet deep, are drilled in the heading. In the meantime the muckers have cleared the tracks, and are shovelling the muck into the cars, or onto the conveying belt where the muck-handling drill carriage is used. Smooth steel plates, called slick sheets, are laid in the bottom of the heading before each blast, for the muck to fall on, so that the muckers shovel off a smooth surface.

Where no drill carriage was used (see figure 13) three muckers threw the muck back from the face to the slick sheets and four shovelled it into the cars. These four men, on each shift of 8 hours, handled all the muck made in that shift. Thus, during the record month, each man handled from 12 to 15 cubic yards of muck per shift, which, considering that about two hours of each shift were lost in blasting, was a most unusual performance.

All blasts are fired electrically from the lighting circuit; the blasting switch and leads being carried on the opposite side of the heading from other electric wires. Where time fuses are not used the rounds are usually fired in four shots; 1st, the cut holes, which form the opening wedge; 2nd, the relieving holes, immediately surrounding the cut; 3rd, the line holes, which break the heading to its full width; 4th, the dry holes, which break the heading to its full height. Sometimes the line holes and dry holes are fired together when the ground is breaking well.

Where time fuses are used the cut is fired in the usual way with ordinary exploders so that if, as is very often the case, the cut does not break to the bottom at the first shot it can be fired a second time.

After the cut has been fired the rest of the heading is loaded with time fuses, cut at two inch intervals, running in length from two inches up. Two of each length of fuse are used around the cut, the shortest fuses being closest to the cut and the longest being the two bottom corner holes so that the muck will be thrown back from the face by the last explosion. These fuses are ignited by electric igniters exactly similar in construction and resistance to the regular electric exploders. Thus all fuses are ignited simultaneously and regular exploders may be discharged at the same time if desired. This method saves time in blasting and leaves the men much fresher than if they had to go back into the smoke again and again. As all the fuses are very short the danger from cut-off holes is practically

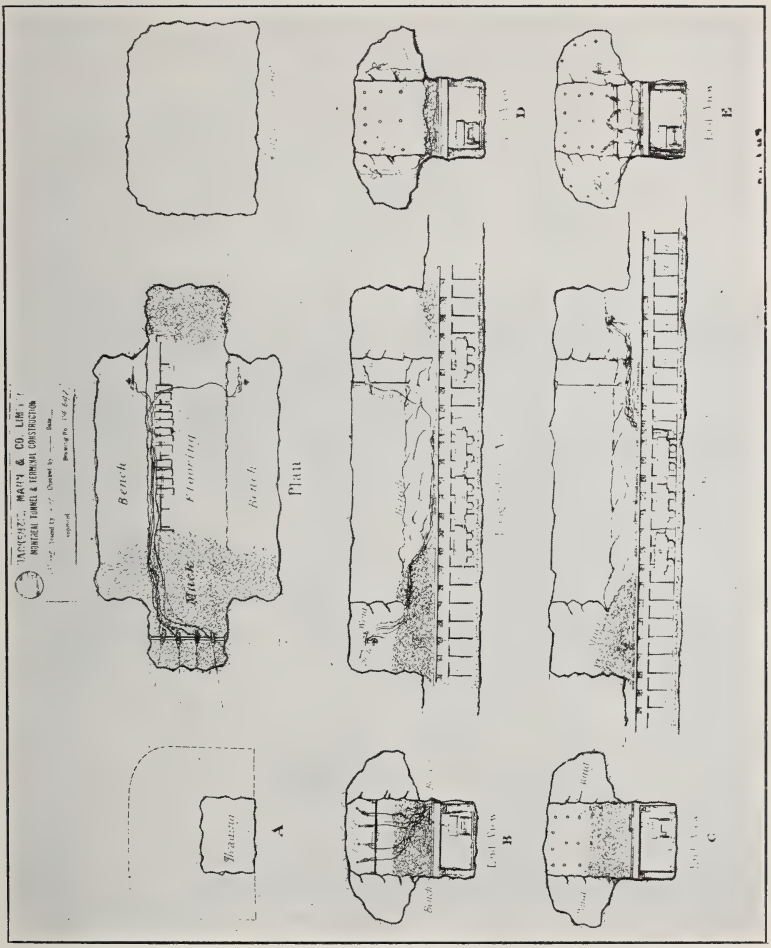


Figure 17—Typical Break-up Procedure

Figure 18—**Break-up Excavation Showing Bottom Heading with Jumbo Timbers.**

eliminated; in fact there has been no trouble from this source whatever thus far. This method is also used in all the Break-ups.

In the heading a round of shots is fired from 3 to 6 times a day (24 hours). During the record month, with three exceptions, six shots were fired every day.

Break-up Excavation.—The Break-ups (see figures 17 and 18) where the upper part of the tunnel section is excavated to its full width and height, are opened at intervals of 500 to 800 feet along the centre bottom heading. As many of these may be opened as are necessary to keep up with the heading progress, the advance in each break-up being about half that in the heading.

In making the Break-up excavation heavy jumbo timbers are framed into the heading, about two feet apart and planked over, so that as the rock is blasted down from above, it can be run through the jumbo timbers into the muck cars in the heading beneath.

In figure 17, "A" shows the location of the heading in the tunnel section. The Break-ups are advanced by carrying an Entry, about 15 feet ahead of the wing wall excavation, the same width of the heading and to the full height of the roof. As seen in "B" figure 17 a horizontal bar is used with 4 drills as in the heading. Immediately after shooting the bar is set up above the muck and the upper half of the entry is drilled. Then the bar is removed to the other end of the Break-up, and while the upper half of that entry is being drilled the muck is removed from the first entry. Thus when the upper half of the second entry is drilled the bar may be set up again in the first entry and the lower half drilled (see "E" figure 17). By the time this drilling is finished the muck is removed from the second entry and the lower half of that may be drilled. In the meantime two columns with a single drill on each are set up in the wings and these drilled so that all the drilling is finished at the same time.

In the limestone two drilling shifts will break all the ground that three mucking shifts can handle economically. As the blasting is always breaking to two faces the drilling is comparatively light and very little powder is required; the powder actually amounting to less than one quarter that required in heading work. The blasting in the Break-ups is done with time fuses which are ignited electrically, as already described. Thus it will be seen that the Break-up Excavation requires but little labor and explosive, being both rapid and economical. With four Break-ups and one heading working at the back of the Mountain the average excavation was about 500 cubic yards of place measurement daily, all of which goes out through the west heading to the main Crusher Plant.

A very important advantage of this method of tunnel driving described herein, as previously mentioned, is that where bad ground is encountered no material delay is experienced. The bottom heading progresses on through the bad material, which is treated carefully and at leisure later on. This saves much time in the ultimate completing, and

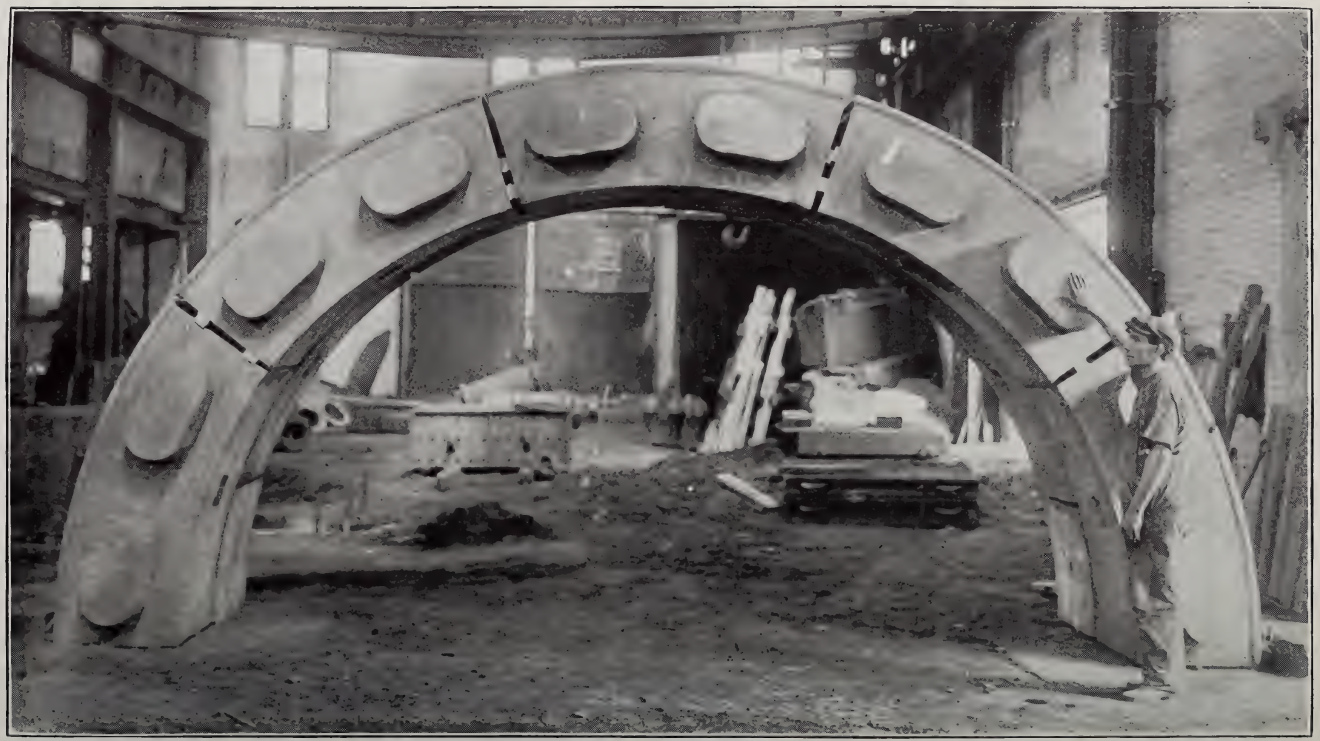


Figure 19—O'Rourke Concrete Block Arch Set Up in Shop.
Showing tenons.

much money and risk in the construction. Some bad ground in Break-ups where heavy internal stresses developed in the roof, require considerable timbering. This will be all concreted in with a reinforced single arch before the steam shovel reaches it, so that neither time nor money will have been lost.

In connection with the physical risk involved by this method it is interesting to note that within 15 months since the tunnel headings were started and with nearly a mile and a half of Break-ups completed there has been only one fatal tunnel accident.

Bench Excavation.—The side benches, below the level of the jumbo timbers, are taken out, after the break-up excavation has been completed, by a steam shovel operated by compressed air. By this method the benches may be drilled and blasted well in advance and by a special loading device the usual delay in spotting cars is avoided, and no time will be lost by the shovel, making this excavation very cheap and rapid.

At places where a steam shovel cannot be used because of timbering, special construction, or shield work, the benches will be handled by hand and a belt conveyor loading into the tunnel cars.

Shield Work.—At the city end where very soft heavy ground is encountered under most unfavorable conditions, a steel roof shield has been adopted. This avoids settlement of over-lying material, reduces the drainage of the surrounding ground, and eliminates the very heavy and expensive timberwork that would otherwise be necessary.

This shield consists of a cutting edge, shaped to conform to the outline of the tunnel roof cross-section, which forms the front of a steel envelope extending over the platforms on which the men work and back far enough to lap over the last "ring" or section of tunnel lining erected. Steel poling boards, semi-attached to the shield will be used, especially in the boulder clay, thus producing a cutting edge that may be advanced in sections where desired.

The shield is supported on steel columns forming the centre wall and on side walls which rest on the solid rock. It is forced ahead by hydraulic jacks, under a pressure of about 5,000 pounds per square inch. These jacks push against the tunnel lining as it is erected.

The procedure is as follows:—

After a shove, i.e., a move of the shield, 27 inches ahead, a ring of concrete blocks, 27 inches wide, along the axis of the tunnel, by 24 inches thick and about 5 feet long circumferentially, are set up in place by means of a hydraulic erector. When this tier of blocks is in place, the jacks are put in motion, jamming the new blocks hard against the last tier erected and forcing the shield slowly ahead, as fast as the ground is excavated in front of it. The excavated material, like that in the breakups, is dropped directly into cars in the heading below. As soon as this shield has made a shove of 27 inches the process is repeated.

Figure 21—**Pneumatic Concrete Placing, in the Tallulah Falls tunnel where this process was used, which is to be tried on the Mount Royal Tunnel.**

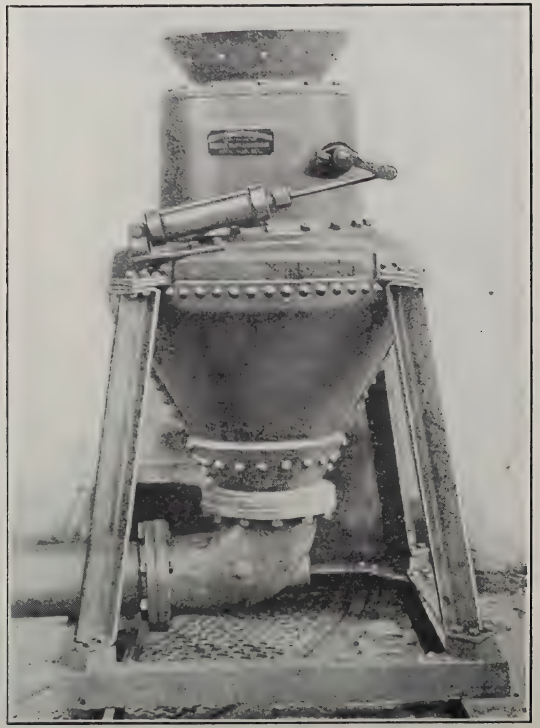


Figure 20—**Pneumatic Concrete Mixer.**

Where boulders are encountered the shield will be retarded and the steel poling boards advanced along the rest of the shield face for the 27 inch shove, when the boulder will have been removed in part or wholly.

Where special rectangular sections are built, a steel structure will be erected and steel sheeting used over and around it. This steel sheeting will be advanced by jacks, the structural steel and enclosing concrete being placed under the sheeting as it advances.

By this method the roof is never exposed; the men are never endangered by falling material, and if water is encountered the face can be protected by poling and breast boards with small pneumatic guns, or jacks, so that very little water or ground can escape.

The blocks used (see figure 19) were invented and patented by John F. O'Rourke of New York, who built the Hudson (North) River Tunnels of the Pennsylvania R.R. They are very massive and so designed that each block locks firmly into the two adjoining ones of the preceding ring, by oval shaped tenons. They are thus self supporting and require no forms such as are usually necessary for concrete work. Since they are moulded many weeks in advance, before being brought into the tunnel, when they are erected under the shield they are sufficiently hard to withstand the thrusts of the jacks without injury. The blocks are also so designed that the extrados of the arch is continuous, but the joints in the intrados are about 1¼ inch wide. These joints are held to shape primarily by 3 part wedges or separators and later filled with mortar by means of a cement gun and grouting.

Pneumatic Concrete Lining.—At the back of the mountain and where the shield is not used it is proposed to try some experiments with mixing and placing concrete by means of compressed air. By this method ordinary forms are used and the concrete is conveyed from the Pneumatic mixer (see figures 20 and 21) to the forms through pipes by compressed air. If this method is successful it should very much reduce the labor required and prove to be both speedy and economical.

All forms used will be collapsible and movable so that they may be used repeatedly. Where convenient and economical steel forms will be used with travelling mechanisms to reduce the labor in handling and settling.

CONSTRUCTION PLANT

Crusher Plant.—All the rock excavated in the tunnel is being crushed for road material and concrete stone. All that is not used by the company or railway is sold for local consumption about Montreal. The main crusher plant at the west portal (see figure 22) consists of two No. 7 Kennedy gyratory crushers with Stevens-Adamson elevators, Conveyors and Screens. The capacity is about 1,600 cubic yards per day. The tunnel muck is hoisted in cars up an incline to tipples. After dumping, the empties

Figure 22—Crusher Plant and Tipple at West Portal.

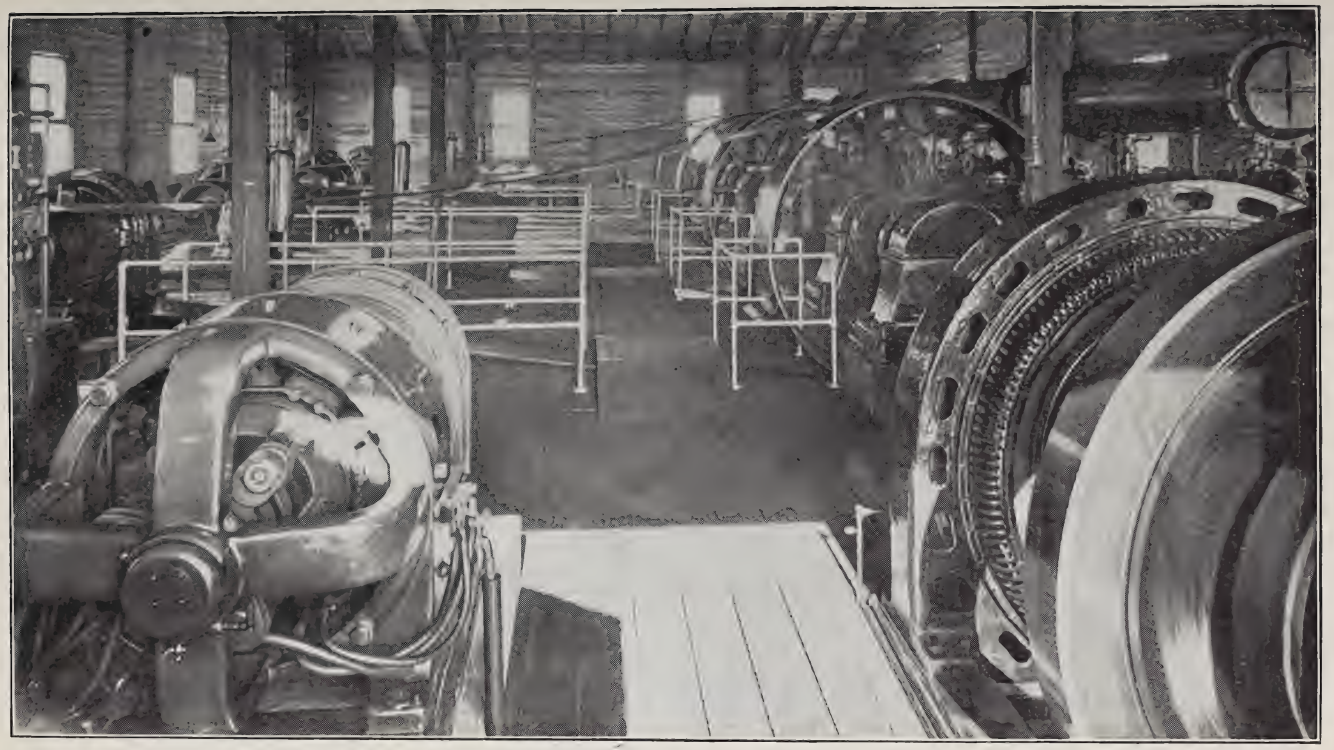


Figure 23—Compressor House at West Portal.

are returned to the tunnel level, through a gravity switchback. The muck passes through the crushers and is elevated to a revolving screen which separates the stone into the various sizes and distributes it by chutes into bins. It can then be run directly into trucks or cars on tracks connected with both the C.P.R. and G.T.R. The overflow is carried on belt conveyors to various stock piles for the different sizes of stone. From these piles the stone is loaded by means of a locomotive crane and clam-shell bucket.

At the city end the tunnel rock is sold as it comes from the tunnel and crushed by an outside company.

Air Compressor Plant.—The compressed air used to operate drills, pumps and other pneumatic machinery is obtained from two plants (see figure 23) one at each end; comprising an aggregate of 11,000 cubic feet of free air per minute compressed to 110 pounds per square inch. These plants consist of 8 cross compound compressors. Six are Blaisdell compressors, belt driven from Canadian General Electric motors, each compressor having a capacity of 1,100 cubic feet. Two are Sullivan Compressors direct connected to Canadian General Electric motors, having a capacity of 2,200 cubic feet each. The power is purchased from the Montreal Light, Heat & Power Co. at 2,300 volts, 60 cycles.

Shops.—Quite elaborate shops were equipped in order to make the job independent of local shops for repairs, and because it was cheaper to build the tunnel cars, of special design, on the job, than to buy them ready made. There was also special machinery such as the drill carriages to be built that would have been more complicated in an outside shop. It was found, too, that in the Company's shop, three electric tunnel locomotives could be built for the price of two from the regular manufacturers and being built to special design enabled them to be used as 5 ton storage battery locomotives or 8 ton trolley locomotives, with very slight changes and at short notice. The shop equipment consists of 3 Ward Drill Sharpeners; one air operated steam hammer; a combined shear and punch for plate work; 3 lathes 60", 24" and 12" respectively; two 36" radial drills; two small power drill presses; two 24" power hack saws; one pipe and bolt machine; one shaper; two emery wheels; two large grind-stones; one oxy-acetylene apparatus; two band saws and two circular saws with the usual equipment of pneumatic and other small tools (see figure 24).

Transportation Plant.—The transportation plant consists of one American Saddle Tank 30 ton "Dinkey" locomotive; two ten ton and one eight ton General Electric trolley locomotives for the tunnel; six 5 ton storage battery tunnel locomotives; two home-made electric tunnel locomotives, interchangeable from 5 ton storage batteries to 8 ton trolley locomotives; 215 tunnel cars, including all types.

One Browning 45 ton 8-wheel locomotive crane.

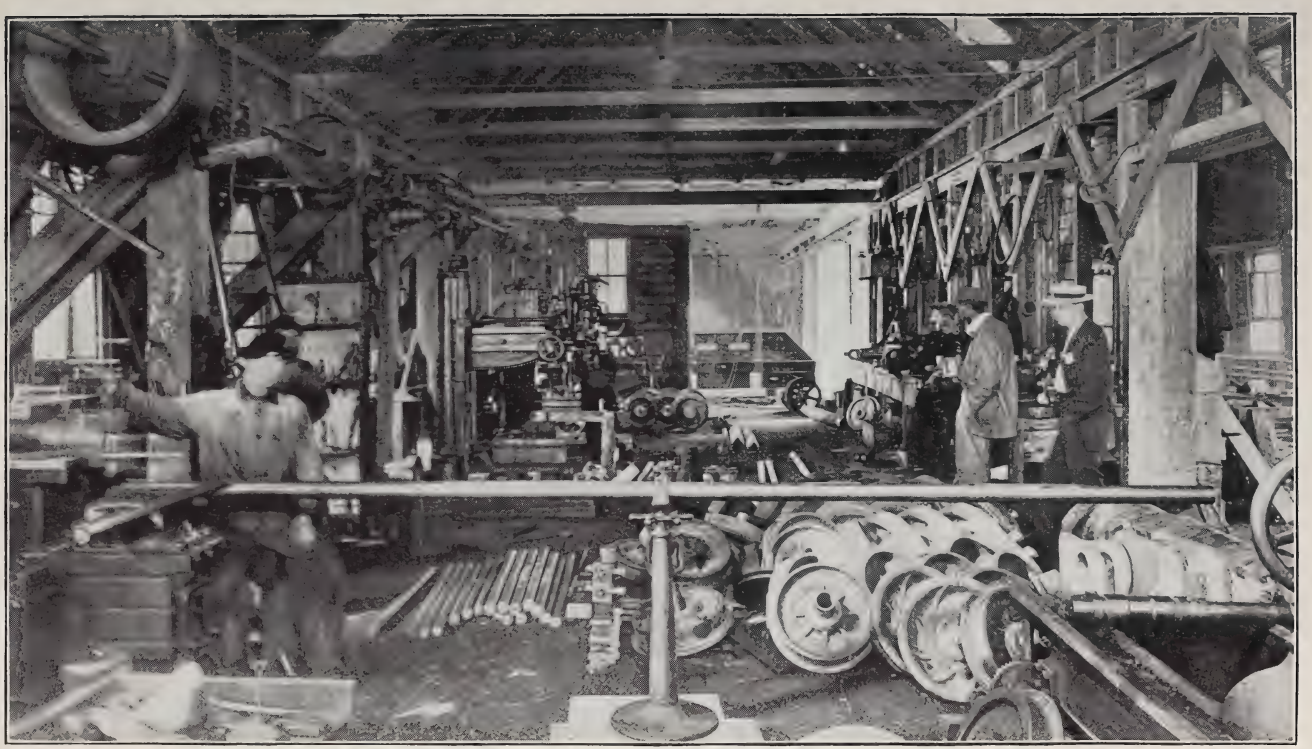


Figure 24—Corner of Machine Shop at West Portal.

Two Lidgerwood Mine Hoists with Eagle Iron Works automatic dumping shaft cages.

The usual equipment of derricks and hoisting engines.

One 7½ ton Commer auto truck.

One 3 ton Alco auto truck.

Two Ford run-abouts.

One 30 Horse Power Cadillac Touring Car.

Drills.—The Main Drilling equipment consists of Sullivan percussive (reciprocating) drills fitted with a water attachment for hollow steel. Many details of these drills were designed especially for this work and are giving remarkably good results.

The best light hammer drill found is the Hardy "Simplex." It is a 25 lb. self-rotating drill that has given most satisfactory results.

A few numerous other makes of drills were tried or purchased principally for experimental purposes.

Miscellaneous Plant.—Cameron reciprocating pumps are used, and are, as always, satisfactory.

Root Blowers are used for ventilating.

Berger Surveying Instruments are being used with most accurate and satisfactory results.

Figure 25—General Panorama at West Portal showing Plant and Camps.

Synopsis

MOUNT ROYAL TUNNEL

Lengths, 3 1-10 miles.
Heading in station site, 1-3 mile.
Grade, 0.6% down towards the city.
Section, 23.5 feet high by 31 feet wide, standard excavation.
Type, Twin tube.
Depth, 600 feet below summit.
Geology, Trenton Limestone and Essexite with igneous dykes.
Method, bottom centre heading and Break-ups.
Progress, best single heading 810 feet in 31 working days, averaging 420 feet per month in each heading.
Gross average 1,100 feet per month.

ESTIMATED QUANTITIES

Tunnel

Excavation, 20,000 cubic yards of earth.
405,000 cubic yards of rock.
Concrete, 50,000 cubic yards.
Steel and Iron, 4,400,000 lbs.
Shafts, Maplewood, 240 feet deep.
Dorchester, 55 feet deep.
Present pay roll, 1,000 employees.
Present daily consumption of 60% dynamite, 2,000 lbs.
Present daily rate of solid excavation, 900 cubic yards.

TERMINAL SITE—Exclusive of Terminal Buildings

Length, 1,200 feet.
Width, 350 feet.
Depth, 50 feet maximum.
Total tracks, 13.
Excavation, 540,000 cubic yards earth.
95,000 cubic yards rock.
Concrete, 100,000 cubic yards retaining walls, track, slabs and platforms.
Reinforcing steel, 3,500,000 lbs.
Structural steel, 8,000,000 lbs.

MOUNT ROYAL HEIGHTS STATION

Length, 500 feet.
Depth, 35 feet maximum.
Excavation, 24,000 cubic yards earth.
7,000 cubic yards rock.
Concrete, 7,000 cubic yards.

ADDENDA

MOUNT ROYAL TUNNEL

ORGANIZATION FOR
MACKENZIE, MANN & Co., LTD.
AND
THE CANADIAN NORTHERN, MONTREAL TUNNEL & TERMINAL Co., LTD.

Principals

SIR WILLIAM MACKENZIE, K.B., President.
SIR DONALD MANN, K.B., Vice-President.

Engineering and Construction Organization

S. P. BROWN, B.Sc., Member: A. S. C. E., C. S. C. E., A. S. M. E. E. A. S. Managing Engineer for Mackenzie, Mann & Co., Ltd.; Chief Engineer of the Canadian Northern Montreal Tunnel and Terminal Co., Ltd.

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R. R. STEVENSON, Instrumentman.
W. H. ABBOTT, Levelman.
Two assistants.

Western Division

R. S. BASSETT, B.Sc., Assistant Engineer.
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C. F. DOORE, Levelman.
Two assistants.

Inspectors

G. C. LECLAIR, Chief Inspector.
W. A. GILMOUR.
M. W. MAXWELL.
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R. L. MUNRO, Cashier.

H. L. HORNE, Chief Storekeeper.

A. E. STRUGNELL, Chief Time Keeper.

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RUFUS GENT, Assoc. A. I. E. E., Master Electrician and Machanic.
JOHN B. ELWOOD, Assoc. A. S. C. E., Efficiency Engineer.

Eastern Division

EDWARD DUFFY, General Superintendent.
C. PHILLIPS, Day Walking Boss.
F. BRAISON, Night Walking Boss.
A. BROWN, Asst. Master Mechanic.
C. GRIFFEN, Chief Electrician.
E. BOSSLET, Boss Carpenter.

Western Division

RICHARD BYERS, General Superintendent.
WM. IRWIN, Night Superintendent.
E. R. FARRELL, Day Walking Boss (Portal).
EDWARD FARRELL, Day Walking Boss (Shaft No. 3).
T. LITTERINI, Night Walking Boss (Portal).
J. PENDERS, Night Walking Boss (Shaft No. 3).
W. R. TINER, Asst. Master Mechanic.
W. T. LESLIE, Chief Electrician.
R. ROBINSON, Yard Boss.
O. SINCLAIR, Boss Carpenter.

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CANADIAN NORTHERN RAILWAY

OFFICERS OF THE TRAFFIC DEPARTMENT

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S. McElmoyle	Freight Claims Agent, Western Lines.	Winnipeg, Man.
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